

(In)Feasability of Studying Ultra-High-Energy Cosmic Rays with Smartphones

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Abstract

We estimate the effective area available for cosmic-ray detection with a network of smartphones under optimistic conditions. To measure cosmic-ray air showers with a minimally-adequate precision and a detection area similar to existing ground-based detectors, the fraction of participating users needs to unrealistically large. We conclude that the prospects of cosmic-ray research using smartphones are very limited.

Interactions of ultra-high-energy cosmic rays (UHECRs) with nuclei of the Earth's atmosphere create an avalanche of secondary charged particles that can be detected on the surface by giant air shower arrays such as the Pierre Auger Observatory [1] or the Telescope Array [2]. Recently it has been proposed to use the camera sensors of smartphones to detect these air showers. The Distributed Electronic Cosmic-Ray Observatory (DECO) [3] aims to use this technique for educational purpose, whereas the CRAYFIS group (Cosmic Rays Found In Smartphones) proposes to employ smartphones for scientific research [4, 5].

Since the flux of UHECRs is very small (of the order of 1 per km² per century), an essential feature for a cosmic-ray observatory is to cover a sufficiently large detection area. In the present short note we study this most basic feasibility requirement for studying ultra-high-energy cosmic rays with an array of smartphones. Additional important issues, if the achievable event rate is sufficient for such a detector to be of scientific interest, are the capability to trigger on air showers, the quality of the event reconstruction, and the reconstruction uncertainties in energy and arrival direction (see also [6]).

The effective area of an array of smartphones *à la* CRAYFIS [5] is given by the total area on the globe where the density of phones participating in the UHECR search exceeds the threshold for cosmic ray detection, weighted by the duty cycle f_{up} of each phone,

$$A_{\text{eff}} = f_{\text{up}} \sum_i A_i \mathcal{H}(f_{\text{sp}} f_{\text{app}} \rho_i - \rho_{\text{thr}}). \quad (1)$$

Here the sum runs over all grid points on the surface of Earth, \mathcal{H} is the Heaviside function, ρ_i denotes the population density in bin i and the area of bin i is given by A_i . f_{sp} and f_{app} are the fraction of the population owning smartphones and running the app respectively. For simplicity, f_{sp} and f_{app} are assumed to be globally constant.

Estimates for the population density ρ_i are provided by the Global Rural-Urban Mapping Project (GRUMPv1) for the year 2000 on a 30 arcsecond grid with an average area per grid point of 0.6 km² [7]. The corresponding population density map is shown in Fig. 1.

The minimal phone density, ρ_{thr} , for detecting UHECR showers with an acceptable energy resolution of $\Delta E/E \lesssim 30\%$ is 5000 phones per km², for a threshold energy of $E > 10^{19}$ eV, and

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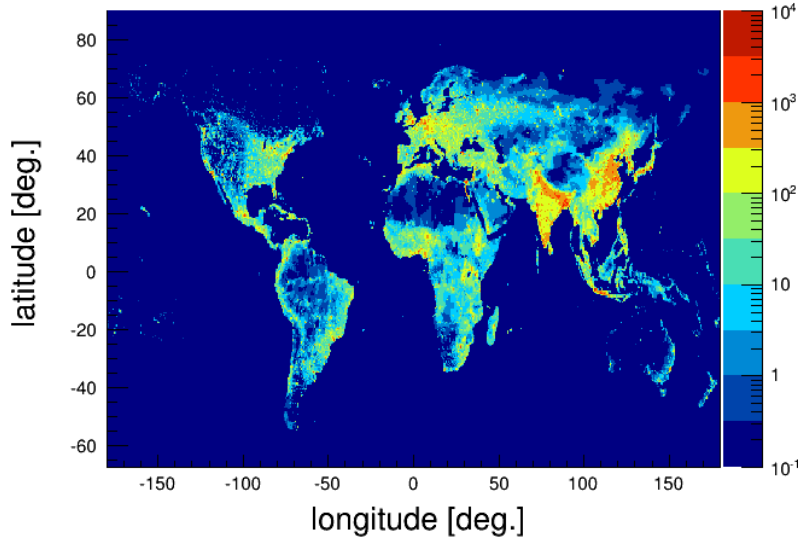


Figure 1: GRUMPv1 population density averaged over $0.5^\circ \times 0.5^\circ$ bins. Densities are capped at $\max(\min(\rho, 10^{-1}), 10^4)$.

1000 phones per km^2 for $E > 10^{20}$ eV, assuming an optimistic value for the effective sensor area of $A_\varepsilon = 5 \times 10^{-5} \text{ m}^2$ (cf. Fig. 7 in [5]).*

The number of active smartphones depends on the fraction of phones running at any given time, f_{up} . Assuming that CRAYFIS is running overnight while the phone is charging, $f_{\text{up}} = \frac{1}{3}$ seems to be a plausible value. Since for each grid point the down time is correlated between phones (no data taking during day time), f_{up} diminishes the overall duty cycle, but does not enter into the Heaviside function in Eq. (1).

The fraction of people owning a smartphone, f_{sp} , varies considerably from country to country. Values for 2013 are 56% for the USA, 47% for China, 17% for India and 14% for Indonesia [8]. In the following we adopt 50% as an optimistic estimate that might be reached in the future.

The most uncertain ingredient of the calculation is the fraction of smartphone owners that install CRAYFIS, f_{app} . As a point of reference, the three popular astronomical apps *SkEye*, *Star Tracker* and *Google Sky Map* accumulate 11-56 million installations together [9]. However, Citizen Science apps, such as *CrowdMag* [10] by NOAA for the monitoring of the Earth magnetic field, can have as few as 1000 - 5000 installations. And even the highly popular desktop-based search for extraterrestrial life, SETI@home, has only a little more than 100,000 active users [11].

The effective area of CRAYFIS as a function of f_{app} is shown in Fig. 2 for two values of ρ_{thr} corresponding to phone densities that allow the detection of air showers above 10^{19} eV and 10^{20} eV. As can be seen, to reach the effective area of the Pierre Auger Observatory, CRAYFIS would have to run with a participation rate of $f_{\text{app}} > 15\%$ if it targeted only very energetic showers above 10^{20} eV. For a lower energy threshold of 10^{19} eV, the participation rate would have to be $f_{\text{app}} > 75\%$.

For comparison, an upper limit of f_{app} for the aforementioned popular astronomical apps is 0.0056 assuming that 1 billion devices running Android OS [12] and that the installation count reflects the actual number of apps in use. Even if the hunt for cosmic rays above 10^{20} eV were as popular as stargazing, the corresponding effective area is zero, because there is no spot on Earth where the population density exceeds $\rho_{\text{thr}} / (f_{\text{sp}} f_{\text{app}}) = 4 \times 10^5$ people per 1 km^2 .

We conclude therefore that unless the popularity and usage of the CRAYFIS app significantly exceeds that achieved by current popular science apps, there is little hope of contributing to the science of ultra-high energy cosmic rays with the smartphone approach.

*It should be noted that even in this case, the energy and angular resolution that could be achieved by CRAYFIS is much worse than for conventional air shower arrays. For instance, the energy resolution of the Pierre Auger Observatory is 12% and the angular resolution is better than 1° [1]. The arrival direction resolution estimated by the CRAYFIS group would be about 20° (10°) in azimuthal (zenith) angle for events with $E = 10^{20}$ eV, and much worse for those at 10^{19} eV [5].

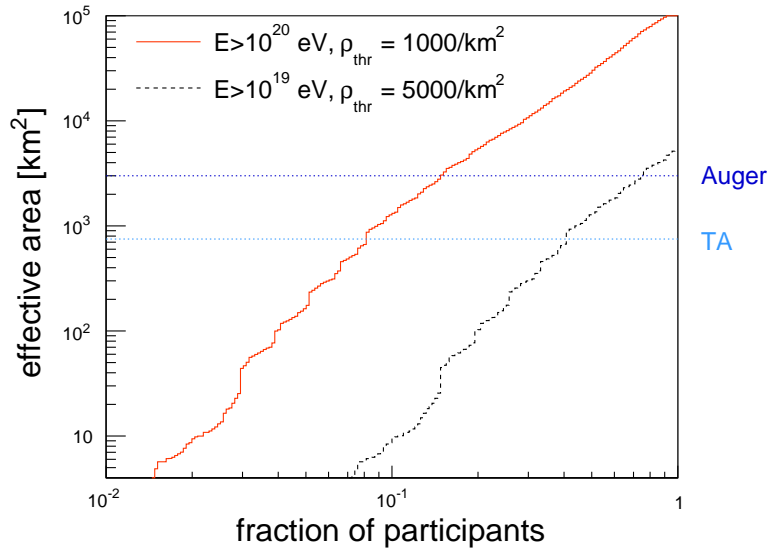


Figure 2: Effective area of CRAYFIS for two energy thresholds as a function of the fraction of smartphone users participating in the UHECR search. Horizontal lines indicate the area of the surface detectors of the Pierre Auger Observatory and the Telescope Array.

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